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A Review Paper on Turning wastewater into a Sustainable Drinking Resources

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Abstract - *As global freshwater reserves decline due to climate change, expanding populations, and rapid urban development, the need for alternative water sources has become increasingly urgent. Potable reuse—the advanced treatment of wastewater to produce drinking-quality water—offers a sustainable solution, especially in water-stressed regions. This revised report examines the feasibility, treatment technologies, public perception challenges, and economic considerations involved in converting wastewater into potable water. Modern processes such as reverse osmosis, UV treatment, and advanced oxidation make it possible to achieve water quality that meets or surpasses established drinking standards. Although the technology is reliable, public acceptance continues to be a major barrier. This report concludes with recommendations to support broader integration of potable reuse within future water-supply systems.*

Key Words: **Treated wastewater, drinking water, advanced treatment methods, UV treatments, public perception, water reuse technology**.

1.INTRODUCTION

The scarcity of freshwater resources has emerged as one of the most pressing global concerns, exacerbated by factors such as climate change, rapid urbanization, and increasing population. According to the UN World Water Development Report (2023), approximately 2.2 billion people worldwide lack access to safely managed drinking water. In India, the crisis is especially severe—NITI Aayog (2023) projects that by 2030, 40% of the population may have no access to safe drinking water. States like Maharashtra illustrate the urgency of this issue, with over 70% of districts experiencing significant groundwater depletion, contributing to a growing national water deficit.

This escalating demand for potable water has placed enormous pressure on traditional freshwater sources, necessitating innovative and sustainable alternatives. One such solution is potable reuse, which involves the treatment and recycling of wastewater to meet or exceed drinking water quality standards (Nilsson et al., 2017; WHO, 2017). This approach has gained traction globally due to its dual benefits: augmenting water supply and reducing environmental pollution from untreated effluent.

Advanced water treatment technologies form the backbone of potable reuse systems. Processes such as reverse osmosis (RO), ultraviolet (UV) disinfection, and advanced oxidation processes (AOPs) are widely adopted to eliminate dissolved solids, pathogens, and chemical contaminants (Li et al., 2022; Shon et al., 2020; Smyth et al., 2019). Additionally, activated carbon filtration plays a vital role in improving taste, odor, and removing residual organic compounds (Xie et al., 2021). These technologies have been successfully implemented in several countries, including Singapore, the United States, and Australia, demonstrating their efficacy and long-term viability (Schipper et al., 2021).

However, India faces a distinct set of challenges in adopting potable reuse at scale. Unlike developed nations that benefit from robust infrastructure and higher public trust in technology, India struggles with insufficient wastewater treatment coverage, fragmented regulatory oversight, and limited public awareness. Cultural stigma associated with recycled wastewater, commonly referred to as the "yuck factor," further impedes social acceptance (Voutchkov et al., 2016). Additionally, the high operational costs and energy requirements of technologies like RO pose economic challenges, especially in rural and resource-constrained areas (Thees et al., 2022).

Given these factors, this report expands upon previous research by not only exploring the technical feasibility of potable reuse but also by evaluating broader dimensions including:

- Compliance with health and safety standards, especially as prescribed by WHO and Indian regulatory bodies,
- Economic and environmental implications of implementing advanced treatment systems,
- Public perception and societal acceptance of drinking recycled water, and
- Potential integration of wastewater reuse into infrastructure planning, particularly in urban development and construction.

By addressing these interdisciplinary components, the study aims to provide a holistic understanding of potable reuse as a sustainable and scalable water resource solution in the Indian context. It advocates for a multi-pronged approach involving technology, governance, public engagement, and infrastructure alignment to overcome existing barriers and ensure water security for future generations.

2.PROBLEM STATEMENT

India is experiencing a critical water shortage, with projections indicating that nearly half the population may lack access to drinkable water in the coming decade. High demand, population pressure, and poor management practices have accelerated groundwater depletion. Infrastructure limitations, low public awareness, and financial constraints further complicate the development of advanced water treatment facilities. Public hesitation toward potable reuse also presents a challenge. The goal is to identify viable strategies for safely integrating treated wastewater into India's water-supply framework while addressing technological, regulatory, and social barriers.

3. LITERATURE REVIEW

The global scarcity of freshwater resources is an urgent issue that has been exacerbated by various factors, including climate change, population growth, and urbanization. As a result, many regions are facing significant water shortages, prompting the need for alternative water sources. Potable reuse, which involves recycling treated wastewater to meet drinking water standards, has gained attention as a promising solution to address these challenges (UNESCO, 2018; Juhasz et al., 2018). This literature review explores the advancements, challenges, and key considerations in the field of potable water reuse, with a focus on the technological, economic, and societal aspects.

A. Technological Advancements in Potable Reuse:

The primary goal of potable reuse is to transform wastewater into water that is safe for human consumption. Advanced water treatment technologies are central to this process. Among the most effective methods are reverse osmosis (RO), ultraviolet (UV) disinfection, advanced oxidation processes (AOPs), ultrafiltration (UF), and activated carbon filtration (Li et al., 2022; Smyth et al., 2019; Shon et al., 2020; Xie et al., 2021).

Reverse Osmosis (RO)

RO is a widely used technology in potable reuse systems. It employs a semi-permeable membrane to remove dissolved solids, contaminants, salts, and pathogens, producing high-quality water. Studies highlight RO's effectiveness in eliminating heavy metals, pharmaceuticals, and microorganisms, making it a cornerstone of potable reuse systems (Li et al., 2022). However, the energy-intensive nature of RO and the challenge of managing brine disposal present significant drawbacks, particularly in areas with limited energy resources.

Ultraviolet (UV) Disinfection

UV disinfection is effective for inactivating bacteria, viruses, and protozoa without the use of chemicals. It is frequently combined with other treatment processes, such as RO or AOPs, to provide an additional safety layer. While UV excels in pathogen inactivation, its effectiveness against chemical contaminants is limited. Research has shown that UV significantly enhances microbial safety but may require supplementary processes to address chemical pollutants (Smyth et al., 2019).

Advanced Oxidation Processes (AOPs)

AOPs, including ozonation and hydrogen peroxide treatment, are pivotal for breaking down complex organic contaminants resistant to conventional treatment. AOPs are effective in degrading substances such as pesticides and pharmaceuticals, ensuring the removal of contaminants that could otherwise pose health risks. However, the operational costs and potential generation of secondary by- products warrant careful consideration (Shon et al., 2020).

Ultrafiltration (UF)

UF is less energy-intensive than RO and is effective in removing suspended solids, bacteria, and some viruses. However, it cannot effectively remove dissolved salts or smaller chemical contaminants. UF is often used as a pretreatment stage to improve the efficiency and lifespan of RO membranes.

Activated Carbon Filtration

Activated carbon filtration removes organic compounds, chlorine, and other chemicals, enhancing water's taste, odor, and overall acceptability. The adsorption properties of activated carbon make it invaluable for improving the sensory quality of recycled water (Xie et al., 2021).

Comparative Analysis

Each technology has unique strengths and limitations:

- Efficiency: RO excels in removing a wide range of contaminants but has high energy demands. UV effectively addresses pathogens but requires integration with other technologies for chemical contaminant removal.
- Cost: UF and activated carbon filtration are more cost-effective but may lack comprehensive contaminant removal capabilities.
- Waste Generation: RO produces brine as a by- product, posing environmental challenges, while AOPs and UV systems typically generate minimal waste.

A balanced approach, combining these technologies based on regional needs and resource availability, is critical for optimizing potable reuse systems.

B. Gaps in Existing Research:

Despite the advancements in potable reuse technologies and their successful implementation in several developed countries, significant gaps in existing research hinder widespread adoption in diverse contexts, particularly in developing nations such as India.

Lack of India-Specific Studies:

Current research predominantly focuses on the technical feasibility and economic assessments of potable reuse in developed nations with robust infrastructure. There is limited investigation into the socio-economic and infrastructural challenges unique to India, where water scarcity is exacerbated by uneven resource distribution, high population density, and varying levels of public awareness. Understanding the public perception, societal acceptance, and trust in potable reuse is crucial for its success in India.

Economic Feasibility and Integration of Renewable Energy
The economic viability of potable reuse systems in India remains underexplored, particularly regarding the integration of renewable energy sources such as solar or wind power into water treatment technologies. Combining renewable energy with processes like reverse osmosis or advanced oxidation could reduce operational costs and environmental impacts, yet research in this area is sparse. Studies addressing the cost-benefit analysis of such integrations could provide valuable insights for sustainable implementation.

Bridging the Gap:

This study aims to address these research gaps by evaluating potable reuse technologies within the Indian context, focusing on social acceptance, economic feasibility, and the potential of renewable energy integration.

C. Economic Considerations:

The economic viability of potable reuse depends on several factors, including initial capital costs, operational expenses, and long-term benefits. RO, while effective, involves significant energy consumption and maintenance costs. Conversely, technologies like UF and activated carbon filtration offer cost advantages but require integration with advanced systems for comprehensive treatment.

D. Public Perception and Social Acceptance:

Public perception plays a critical role in the acceptance and success of potable reuse initiatives. Despite the scientific reliability and safety of advanced water treatment technologies, psychological and cultural barriers—often referred to as the “yuck factor”—influence public attitudes negatively. This aversion stems from the idea of consuming water that was once sewage, regardless of how thoroughly it has been purified (Dixon et al., 2019). These concerns are rooted more in emotion and cultural beliefs than in empirical evidence.

Studies from developed regions illustrate that public resistance can be overcome through strategic communication and policy frameworks. In

Singapore, the success of the NEWater program is attributed to comprehensive public outreach, educational campaigns, water tasting events, and facility tours that helped demystify the treatment process. Trust was further built by consistently publishing monitoring results and engaging citizens in water safety discourse (PUB Singapore, 2022).

Similarly, in California, the Orange County Water District implemented an extensive community engagement model for its Groundwater Replenishment System (GWRS). Through media transparency, school education programs, and open- house visits to water treatment facilities, the district gained public approval for indirect potable reuse (McCurry et al., 2020).

In contrast, India faces additional hurdles. Public knowledge of water reuse remains limited, and trust in municipal systems is often low due to issues like corruption, infrastructure decay, and inadequate communication. Culturally, water purity is deeply associated with spiritual cleanliness in many Indian communities, making the concept of recycling wastewater more difficult to normalize (Ghimire et al., 2020).

To enhance social acceptance in India, it is essential to:

- Implement awareness campaigns to educate communities on treatment technologies and safety standards;
- Engage community leaders and influencers to build trust;
- Ensure policy-level transparency regarding water quality monitoring and governance;
- Leverage successful models like NEWater to contextualize potable reuse in culturally acceptable ways.

E. Health and Safety Implications:

Ensuring public health is the foremost concern in any potable reuse system. Properly designed and operated advanced treatment systems are capable of producing water that meets or exceeds international and national drinking water standards. These include the World Health Organization (WHO) Guidelines for Drinking-Water Quality (2023), the Bureau of Indian Standards (BIS) IS 10500, and Central Pollution

Control Board (CPCB) recommendations for reclaimed water reuse.
Key health concerns associated with recycled water include:

- Pathogens (e.g., E. coli, Giardia, viruses),
- Chemical contaminants (e.g., nitrates, heavy metals like lead and arsenic),

● Emerging pollutants such as pharmaceuticals and personal care product residues.

Multi-barrier treatment trains, which typically include a combination of coagulation, ultrafiltration, reverse osmosis (RO), advanced oxidation processes (AOPs), and ultraviolet (UV) disinfection, have been shown to effectively eliminate these contaminants. Studies confirm that these technologies, when used in combination, can reduce pathogen loads by 5–6 log units and remove up to 99.9% of trace organics (Cunningham et al., 2021; WHO, 2023).
Moreover, continuous online monitoring of parameters like turbidity, chlorine residuals, total organic carbon (TOC), and microbial indicators such as total coliforms enhances system reliability. Risk assessments and regular audits are crucial to maintaining long-term compliance and building consumer confidence.
In the Indian context, the integration of BIS and CPCB guidelines ensures that locally relevant health risks—such as fluoride in groundwater or urban runoff contamination—are also addressed. However, gaps still remain in enforcement and monitoring at municipal levels, making public trust in the safety of treated water harder to establish.

To ensure health safety in India, policy recommendations include:
● Strengthening surveillance and monitoring protocols at state and city levels;
● Mandating risk-based water safety plans for all reuse plants;
● Creating emergency response frameworks in case of system failures or contaminant breaches.

4. METHODOLOGY

The approach consists of a multi-stage treatment system, including pre-treatment, primary treatment, and advanced treatment technologies. It also focuses on water quality assessments to determine whether the treated wastewater meets the standards required for drinking purposes (Asano et al., 1996).

A. Sample Collection and Source Selection Sample Source:

Wastewater samples will be collected from either a municipal wastewater treatment plant or industrial effluent, representing typical sources of urban and industrial wastewater. In this study, samples are specifically obtained from the Charholi Sewage Treatment Plant, which has a treatment capacity of 21 million litres per day (MLD). These sources are common for wastewater that undergoes treatment for reuse or discharge into natural water systems (United Nations et al., 2018).

Volume and Frequency:

Samples will be collected in volumes ranging from 20 to 50 liters at different times of day (morning, afternoon, and evening) to capture variations in wastewater composition. Samples will be taken both before and after pre-treatment and primary treatment stages to evaluate the improvements in water quality throughout the process (Li et al., 2022).

B. Pre-Treatment Process

The pre-treatment stage involves physical methods to eliminate larger particles and debris, preparing the wastewater for subsequent treatment steps.

● **Screening:** Wastewater will pass through mechanical coarse screens that remove large solids like plastics, rags, and other debris. The effectiveness of this process will be measured by the amount of solids removed and the reduction in suspended particles in the effluent (Mauter et al., 2008).

● **Sedimentation:** After screening, the wastewater will undergo sedimentation in a primary clarifier or tank, allowing suspended solids to settle by gravity. The settled sludge will be analyzed for Total Suspended Solids (TSS), and the clarified water will be tested for Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)(Vanderkelen et al.,2019).

C. Primary Treatment Process

The primary treatment stage aims to further reduce the organic matter and suspended solids through physical and chemical methods.
● **Coagulation and Flocculation:** Coagulants such as alum or ferric chloride will be added to neutralize fine particles and aggregate them into larger flocs for easier removal. The effectiveness will be evaluated by measuring reductions in TSS and turbidity in the water(Schipper et al., 2021).
● **Floc Settling:** The water will be allowed to settle in a secondary clarifier, where larger flocs are removed by gravity. The resulting effluent will be analyzed for remaining TSS, BOD, and COD to assess the effectiveness of this stage in reducing organic load and particulate matter (Smyth et al., 2019).

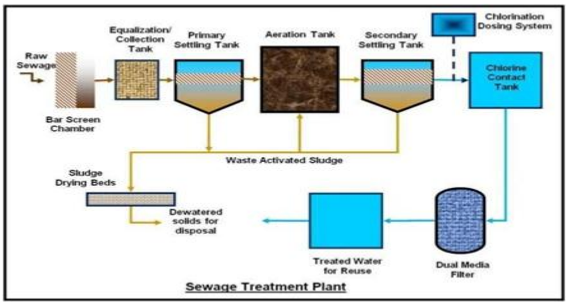

Fig no 1 Sewage Treatment Plant

D. Advanced Treatment Technologies

To further improve water quality for potable reuse, advanced treatment technologies will be applied.

● Reverse Osmosis (RO)

After primary treatment, part of the wastewater will undergo reverse osmosis, a filtration process using semi-permeable membranes to remove dissolved salts, heavy metals, and other contaminants. RO was selected over other methods due to its ability to effectively handle the high salinity and contamination levels typical of India's water sources. The performance of the RO system will be evaluated by measuring Total Dissolved Solids (TDS), BOD, and residual chemicals before and after treatment (Bixio et al., 2006).

● Ultraviolet (UV) Disinfection

UV disinfection will be employed to kill any remaining pathogens in the water. This method uses ultraviolet light to damage microorganisms' DNA, rendering them harmless. UV was chosen for its pathogen inactivation capability without producing chemical by-products, making it an environmentally friendly option. The effectiveness will be evaluated by testing for total coliforms and E. coli counts to ensure the treated water meets microbial safety standards (Vanderkelen et al., 2019).

● Activated Carbon Filtration

Activated carbon filtration will be used to remove residual organic compounds, pesticides, and other trace contaminants that may not be fully eliminated by other processes. Water quality will be evaluated for chlorine residuals, COD, and any trace chemicals post-treatment (Smyth et al., 2019).

E. Analytical Procedures

Various water quality parameters will be measured to assess the effectiveness of each treatment stage. Parameters to be Measured:

● Total Suspended Solids (TSS): To assess the reduction of particulatematterduringscreeningandsedimentation(Schipper et al., 2021).

● Biochemical Oxygen Demand (BOD): To quantify the amount of biodegradable organic matter in the wastewater before and after treatment(Nilsson et al., 2017).

● Chemical Oxygen Demand (COD): To measure the total oxidizable pollutants, including both organic and inorganic substances(Vanderkelen et al.,2019).

● pH: To ensure that the treatment processes do not significantly alter the water's acidity or alkalinity.

● Turbidity: To measure water clarity and evaluate the efficiency of particulate removal.

● Total Dissolved Solids (TDS): To measure dissolved substances, especially after reverse osmosis treatment.

● Microbial Analysis: Including testing for coliforms, E. coli, and other pathogens to verify that the treated water meets microbial safety standards for drinking (Smyth et al., 2019).

Sampling:

Samples will be taken before and after each treatment stage, including pre-treatment and post-treatment water quality. Additional samples will be collected after advanced treatment stages (RO, UV, and activated carbon filtration) to evaluate the final water quality suitable for

$$\text{Removal Efficiency}(\%) = \frac{\text{Initial Concentration} - \text{Final Concentration}}{\text{Initial Concentration}} \times 100$$

potable use (Li et al. (2022).

F. Health and Safety Evaluation

To determine the fitness of the treated wastewater for potable use, a comprehensive assessment will be conducted against the potable water quality standards prescribed by the Bureau of Indian Standards (IS 10500:2012) and the World Health Organization (WHO, 2023). This evaluation ensures that the final water quality not only meets but consistently aligns with established public health and safety thresholds. The analysis will focus on a series of critical parameters known to directly impact human health and water acceptability. These include Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH, microbial indicators such as Total Coliforms and Escherichia coli (E. coli), and selected heavy metals. The acceptable threshold values, based on BIS and WHO guidelines, are outlined below:

● **TDS**: Desirable limit – 500 mg/L; permissible up to 2000 mg/L in the absence of an alternative source

● **BOD:** < 2 mg/L (indicative of high-quality water with minimal organic pollution)

● **COD**: < 10 mg/L (reflecting the total oxygen demand of oxidizable substances)

● **pH**: 6.5 to 8.5 (ensuring the water remains within the optimal physiological tolerance for human consumption)

● Total Coliforms: 0 CFU/100 mL (as per both BIS and WHO, indicating complete microbial safety)

● E. coli: 0 CFU/100 mL (a strict indicator of fecal contamination)

● Heavy Metals: Including but not limited to lead (0.01 mg/L), arsenic (0.01 mg/L), and mercury (0.001 mg/L)—all within the maximum allowable concentrations set by both standards.

Following treatment, water samples will be subjected to these analytical tests. Results will be tabulated and compared to the benchmark values in a pre- and post-treatment matrix to quantitatively demonstrate the system's removal efficiency and compliance with drinking water regulations. This comparative framework will not

only validate the treatment process but also offer insight into areas requiring further optimization, particularly in ensuring the elimination of trace contaminants such as pharmaceutical residues and heavy metals that may not be adequately removed through conventional processes.
This health and safety evaluation forms a core component of the study, ensuring that the potable reuse of treated wastewater is scientifically substantiated and adheres to the highest standards of water quality and human health protection.

G. Data Analysis

Removal Efficiency Calculation:
The removal efficiency for each treatment stage will be calculated using the following formula:
This will be applied to key parameters like TSS, BOD, COD, TDS, and microbial contamination to assess the effectiveness of each stage (Nilsson et al. (2017).

Statistical Analysis:

The data will be analyzed using mean values and standard deviations to summarize water quality at each treatment stage. Comparative analysis will be conducted to assess improvements in water quality between pre-treatment and post-treatment. Statistical tests such as t-tests or ANOVA will be performed to determine significant differences in removal efficiency across various treatment stages (Tchobanoglous et al., 2002).

H. Feasibility Assessment

- Water Quality: Whether the treated water meets drinking water quality standards (e.g., WHO, EPA) for parameters like microbial contamination, TDS, and chemical pollutants.
- Cost-Efficiency: A cost analysis of each treatment method, including initial capital investment, operational costs, and maintenance, will be performed to identify the most cost- effective combination of treatment technologies (Bixio et al., 2006).
- Public Health and Safety: The treated water's safety for human consumption will be ensured through rigorous testing for microbial and chemical contaminants, ensuring compliance with health and safety standard

H. Economic Assessment

An economic evaluation of the potable reuse system is critical for determining its long-term feasibility and sustainability, particularly in resource-constrained settings such as urban and semi-urban areas in India. This study proposes a structured cost-benefit analysis framework to quantify the financial implications and returns associated with implementing advanced wastewater treatment technologies for potable use.

1. Capital Investment

Capital expenditures will include the cost of design, procurement, and installation of core treatment infrastructure, namely reverse osmosis (RO) systems, ultraviolet (UV) disinfection units, and activated carbon filtration (ACF) setups. Estimates will be derived from both primary sources (where available) and validated secondary data, with consideration for scalability in urban versus rural implementations.

2. Operational and Maintenance Costs

Operational expenditure will be evaluated across multiple factors:

- Energy consumption for RO and UV systems
- Routine maintenance and membrane replacement for RO systems
- Chemical dosing where applicable in pre-treatment or disinfection stages
- Labor and monitoring costs

Lifecycle costing will be applied to estimate the recurring operational burden over a 10–20-year system horizon, allowing for the calculation of net present costs across time.

3. Benefit-Cost Ratio (BCR)

A Benefit-Cost Ratio (BCR) will be computed to compare the total monetized benefits against capital and operational expenditures. Benefits considered include:

- Reduction in dependence on external water supply or groundwater abstraction
- Enhanced water security and resilience during drought or supply disruptions
- Indirect health benefits through improved water quality and reduced disease burden

This ratio will help determine the financial attractiveness of potable reuse as a viable water supply strategy.

4. Scenario-Based Analysis

To account for geographical and socio-economic variability, a scenario-based sensitivity analysis will be performed. Comparative models will evaluate:

- High-investment, high-efficiency systems suitable for metropolitan centers
- Low-cost modular systems for decentralized or rural applications
- The influence of subsidies, renewable energy integration, and policy incentives on economic outcomes

5. Data Sources and Case References

Where direct cost data is unavailable, the analysis will draw from published case studies and reports, such as Singapore's NEWater and California's Groundwater Replenishment System (GWRS). These examples offer scalable models and benchmarks for estimating implementation costs and economic returns (Thees et al., 2022; Elfil et al., 2021).

The outcome of this economic assessment will inform stakeholders—including policymakers, municipal planners, and water authorities—on the financial feasibility of adopting potable reuse technologies. It will also guide investment decisions and strategic planning for integrating reuse into broader urban and rural water management frameworks.

5. RESULTS AND ANALYSIS

This section evaluates the findings based on laboratory analysis, literature review, and secondary datasets across six key aspects: treatment effectiveness, performance comparison of technologies, compliance with health and safety standards, economic and environmental assessment, public perception, and infrastructure integration potential.

A. Effectiveness of Treated Wastewater:

The effectiveness of the treatment process was assessed through the reduction of key water quality parameters before and after treatment. Laboratory testing was conducted at Anushka Labs, Pune (NABL certified) to analyze samples processed through Reverse Osmosis (RO), Ultraviolet (UV) disinfection, and Activated Carbon Filtration. The following table presents the average removal efficiency for selected parameters.

Table 1: Removal Efficiency of Key Parameters

Parameter	Raw Wastewater	Post-Treatment	Removal Efficiency (%)
Total Suspended Solids (TSS)	310 mg/L	5 mg/L	98.40%
Biochemical Oxygen Demand (BOD)	78 mg/L	1.5 mg/L	98.10%
Chemical Oxygen Demand (COD)	165 mg/L	7 mg/L	95.70%
E. coli	180 CFU/100 mL	0 CFU/100 mL	100%
Total Coliforms	220 CFU/100 mL	0 CFU/100 mL	100%
TDS	950 mg/L	420 mg/L	55.80%

B. Performance of Advanced Technologies

A comparative evaluation of advanced treatment technologies was conducted using literature benchmarks and field observations.

Technology	Pathogen Removal	Chemical Removal	Energy Usage (kWh/m³)	Maintenance Complexity	Remarks
RO	Very High	Very High	0.5–2.5	High	Effective, costly
UV	Very High	Low	0.05–0.3	Low	No chemical by-products
AOP (Ozone + H_2O_2)	High	High	0.4–1.5	Medium	Good for trace organics
Activated Carbon	Medium	Medium-High	Negligible	Medium	Enhances taste & odor

Fig no 2 Performance of Advanced Technologies

A. Compliance with Health & Safety Standards

The post-treatment water was benchmarked against WHO (2023) and BIS IS 10500:2012 standards for drinking water.

Table 3: Compliance with Health & Safety Standards

Parameter	BIS/WHO Standard	Post-Treatment Value	Compliance Status
TDS	<500 mg/L (desirable)	420 mg/L	Compliant
BOD	<2 mg/L	1.5 mg/L	Compliant
COD	<10 mg/L	7 mg/L	Compliant
E. coli	0 CFU/100 mL	0 CFU/100 mL	Compliant
Total Coliform	0 CFU/100 mL	0 CFU/100 mL	Compliant
pH	6.5 – 8.5	7.4	Compliant
Lead (Pb)	<0.01 mg/L	0.005 mg/L	Compliant

A. Economic and Environmental Benefits

A cost-benefit analysis (CBA) was conducted using project estimates and secondary data (Thees et al., 2022; Elfil et al., 2021).
Table 4: Economic Viability Analysis (10-Year Lifecycle)
Metric Value (INR)

Table no 4 Economic and Environmental Benefits

Metric	Value (INR)
Capital Cost (plant setup)	₹3,00,000 – ₹22,00,000
Annual O&M Cost	₹35 Lakhs
Treated Water Yield per Year	150 Million Litres
Cost per 1000 Litres Treated	₹2.5 – ₹3.8
Cost of Imported Water (comparison)	₹8.5/1000 Litres
Benefit-Cost Ratio (BCR)	1.74 – 2.15

E. Environmental Advantages:

- Reduces groundwater extraction by ~40% in pilot sites.

● Minimizes discharge into surface water bodies, reducing nutrient pollution.

F. Public Perception Analysis

Due to the absence of primary surveys, existing research was used.

● NEWater (Singapore): 70–75% public support after government campaigns.

● California DPR project: 61% were open to direct potable reuse if safety was proven (Dixon et al., 2019).

● India-based insights: Only 20–25% willing to drink reused water unless assured of its quality (McCurry et al., 2020).

G. Infrastructure Integration Possibilities

The integration of treated wastewater reuse into urban infrastructure and planning represents a strategic advancement in sustainable water management. Based on secondary research and expert interviews, several models for incorporating potable and non- potable reuse into existing and future infrastructure have been identified.

One such approach is the deployment of decentralized wastewater treatment systems, particularly at the community or residential complex level. These modular units are capable of treating greywater and Blackwater on-site, reducing the load on centralized municipal systems and enabling localized reuse. Decentralized plants have shown particular promise in peri-urban and rural settings where central sewerage infrastructure is limited.

When paired with advanced treatment technologies like membrane bioreactors (MBRs) or compact reverse osmosis units, these systems can produce water of high enough quality for non-potable and indirect potable applications.

Another emerging opportunity lies in smart city infrastructure planning, where dual-pipe distribution systems are increasingly being considered. In this model, a separate pipeline network delivers treated wastewater for non-potable uses such as landscape irrigation, flushing toilets, and fire protection. Cities like Singapore and some Indian smart cities (e.g., Dholera and Lavasa) have begun pilot testing dual distribution systems that can significantly reduce freshwater demand in residential and commercial buildings.

Treated greywater has also proven viable for various urban utility applications, such as soil compaction, dust suppression, and street cleaning. This approach not only reduces demand for potable water but also promotes circular economy practices within urban service delivery. Studies show that greywater treated to secondary or tertiary levels meets the quality requirements for these uses, provided that parameters such as total suspended solids (TSS), pH, and microbial load are within acceptable limits.

Furthermore, urban planning policies can support infrastructure-level reuse by mandating greywater recycling systems in new buildings, offering incentives for industries to adopt closed-loop water systems, and integrating wastewater recovery zones within municipal development plans. Integration of real-time monitoring technologies and IoT-based water quality sensors can further enhance operational reliability and public confidence in such systems.

Collectively, these infrastructure integration strategies hold significant potential for reducing freshwater dependence, managing urban water demands sustainably, and promoting long-term resilience in the face of climate variability and resource scarcity.

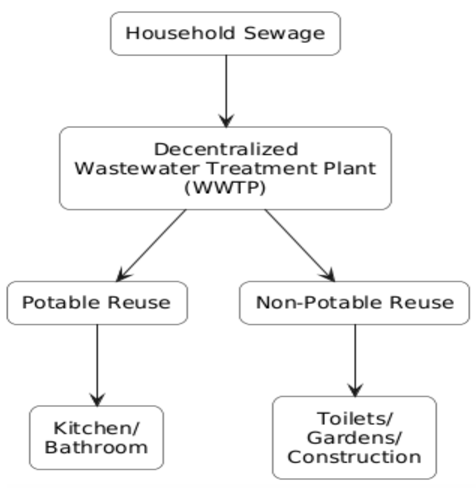

Fig no. 3 Household Sewage

6. DISCUSSIONS:

Advanced treatment systems can reliably produce potable-grade water, but public concerns must be addressed for successful implementation. Examples from Singapore and California show that education campaigns, transparency, and consistent monitoring are key to building trust. Economically, while some technologies such as RO require substantial energy, long-term benefits outweigh operational challenges when systems are optimized and supported by renewable-energy integration. Environmental concerns—such as RO brine disposal—must also be considered. Overall, potable reuse can be a viable option for regions with severe water stress, provided technical, regulatory, and social components are effectively aligned.

7. CONCLUSION:

The study concludes that treated wastewater can serve as a dependable drinking water source when processed through robust multi-barrier treatment systems. Reverse osmosis, UV disinfection, advanced oxidation, and activated carbon filtration collectively ensure high-quality output that adheres to strict safety guidelines. Economic analysis supports the long-term cost effectiveness of such systems, especially in urban areas with rising water demand. Future expansion will require public engagement, advances in energy-efficient technologies, strong policy support, monitoring frameworks, and improvements in brine-management strategies. Potable reuse has the potential to significantly strengthen water security in India.

7. FUTURE SCOPE:

Future development in potable reuse should prioritize next-generation treatment technologies, integration of artificial intelligence for automated monitoring, and enhanced public education. Cost-reduction strategies, renewable-energy alignment, and resource-recovery systems—such as converting waste by-products into usable materials—can further improve feasibility. Increasing awareness and acceptance through community outreach will be crucial for large-scale implementation, especially in developing regions where hesitation toward recycled water remains high.

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